National Spent Nuclear Fuel Program

Advanced Neutron Absorber Development

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Providing for safe, efficient disposition of DOE spent nuclear fuel

Ni-Cr-Mo-Gd Alloy Development

- ASTM status
- ASME status
- Research program results
  - Microstructural features and corrosion performance studies
  - Plate mechanical properties
  - Welding trials
- FY-05 plans
- Summary

Project Overview

Problem:

- Some types of US DOE spent nuclear fuel (SNF) contain highly enriched uranium
- The repository may require criticality control during the regulatory period

Approach:

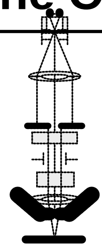
- SNF will be packaged in standardized canister with baskets fabricated from thermal neutron absorbing materials

Benefits:

- DOE SNF is critically safe under fully flooded conditions
- Decreased number of SNF packages going to repository with reduced handling and materials costs.

Project Workflow

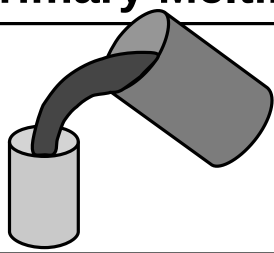
Define Compositions



Laboratory Evaluations

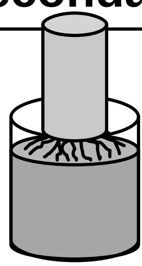
Fe-Ni-Cr-Gd
Ni-Cr-Mo-Gd

Primary Melting and Casting



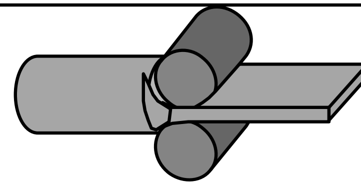
Vacuum Induction Melting (VIM)

Secondary Melting/Refining



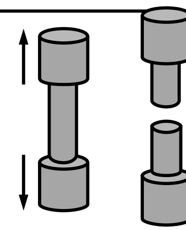
Vacuum Arc Remelting (VAR)

Hot Working/Rolling



Hot Ductility
Forging
Rolling

Properties Testing



Tensile
Charpy Impact
Corrosion
Weldability
Neutronics

Codes and Standards

ASTM Specification
ASME Code Section III
Commercialization

Project Status

- ASTM Material Specifications for Ni-Cr-Mo-Gd Alloy have been issued (B932-04).
- Initiating ASME Code Case Inquiry actions.
- The ASME data package was submitted to ASME Section III, Division 3 (Nuclear Packaging) for nonwelded construction.
- Continuing mechanical properties/ microstructure/corrosion/weldability investigations.

Code Case Path

Sub-Group NUPACK, Section III, Division 3

- Sub-Group Non-Ferrous Alloys, Section II
- Sub-Group Materials, Fabrication & Examination, Section III
- Sub-Group Design, Section III
- Sub-Group Toughness, Section II/VIII

- Sub-Committee Materials, Section II
- Sub-Committee Nuclear Power, Section III

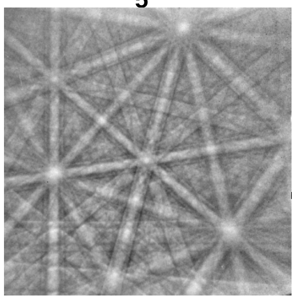
Heat Chemistries

Element	M326	M337	M338	M339	M340
Mo	14.53	14.51	14.55	14.50	14.34
Cr	14.71	15.70	15.70	15.71	15.69
Gd	2.00	2.06	2.05	1.9	2.01
O	0.0032	0.0041	0.0027	0.0038	0.0064
Mn	<0.001	<0.001	<0.001	<0.001	<0.001
Mg	0.002	0.002	0.002	0.003	0.002
Ni	Bal.	Bal.	Bal	Bal.	Bal
Fe	0.025	0.012	0.025	0.006	0.010
Co	0.009	<0.001	<0.001	0.001	0.003
C	0.006	0.0057	0.0066	0.0064	0.0074
Si	0.013	0.007	0.006	<0.005	0.007
S	<0.001	<0.001	<0.001	<0.001	<0.001
N	0.0041	0.012	<0.001	<0.001	0.0016
P	<0.001	<0.005	<0.005	<0.005	<0.005

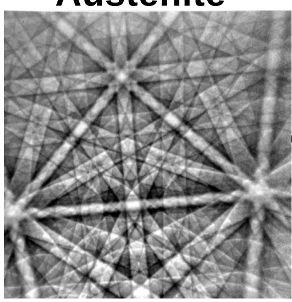
Note: M337-M340 used for ASME Code Inquiry.

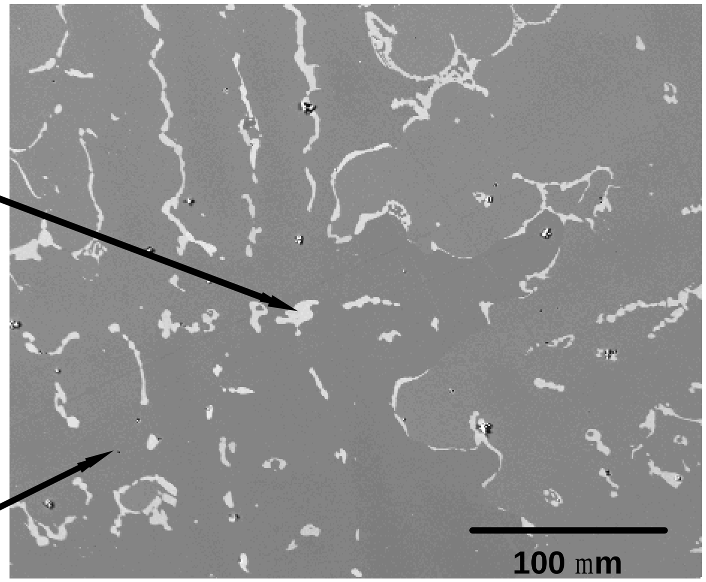
Typical as-cast microstructure of Ni-Cr-Mo-Gd alloys

Ni_5Gd



Nickel Austenite



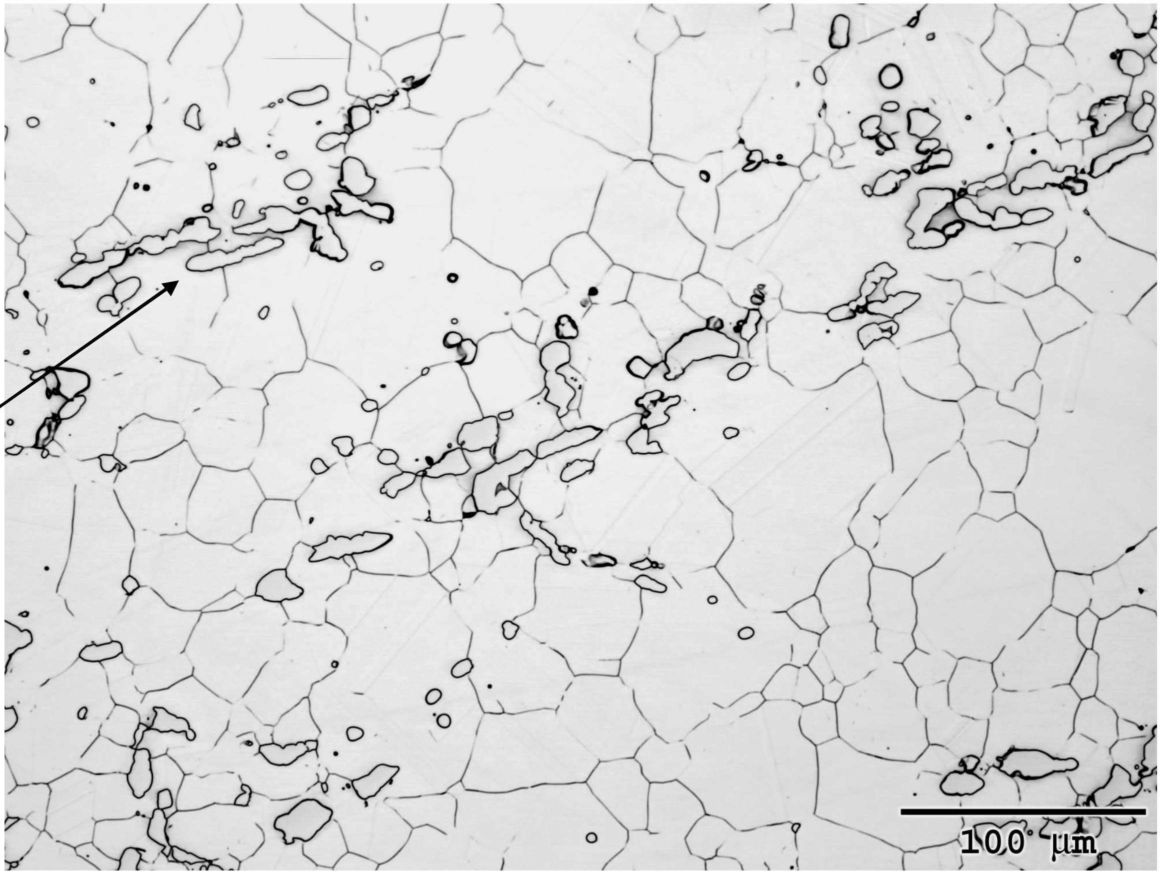


Element	Nominal ASTM Chemistry	Gadolinide
Mo	14.9	0.69
Cr	15.1	2.00
Fe	1.0 max	0.04
Co	0.3 max	---
C	0.010 max	---
Si	0.08 max	0.08
Mn	0.5 max	0.00
P	0.01 max	---
S	0.005 max	---
Ni	bal	63.13
N	0.010 max	---
Gd	2.0	35.26

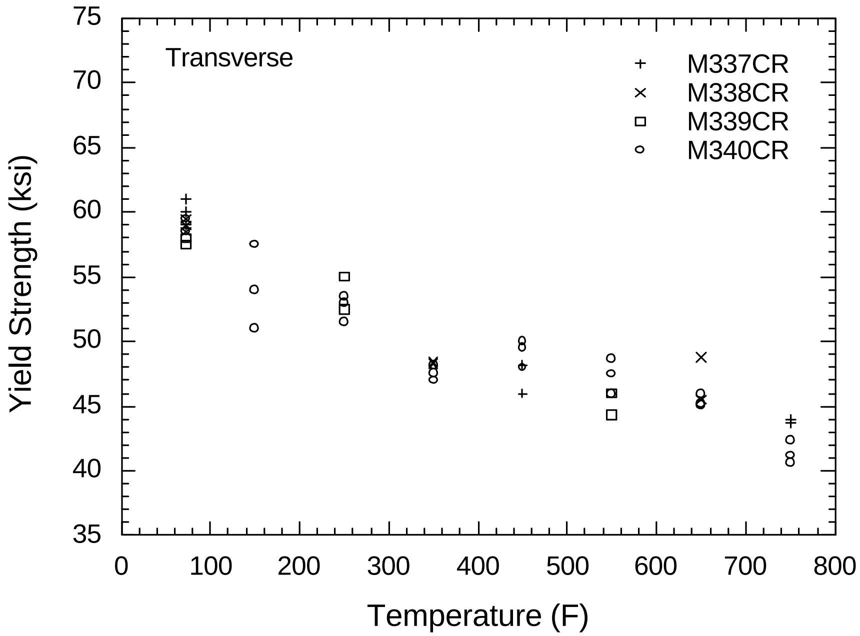
- Composition of gadolinide was similar for a range of melt chemistries - No gadolinium observed in matrix
- Matrix composition can be controlled by adjustment of bulk chemistry

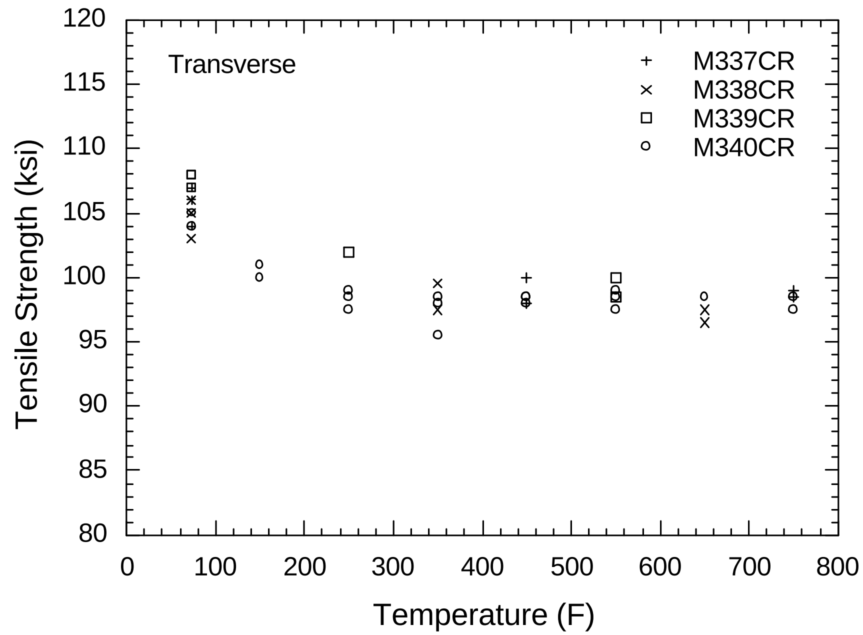
LOM of Heat M340 plate (as-rolled)

(Ni,Cr)5Gd



Transverse Tensile Data for Cross Rolled Heats





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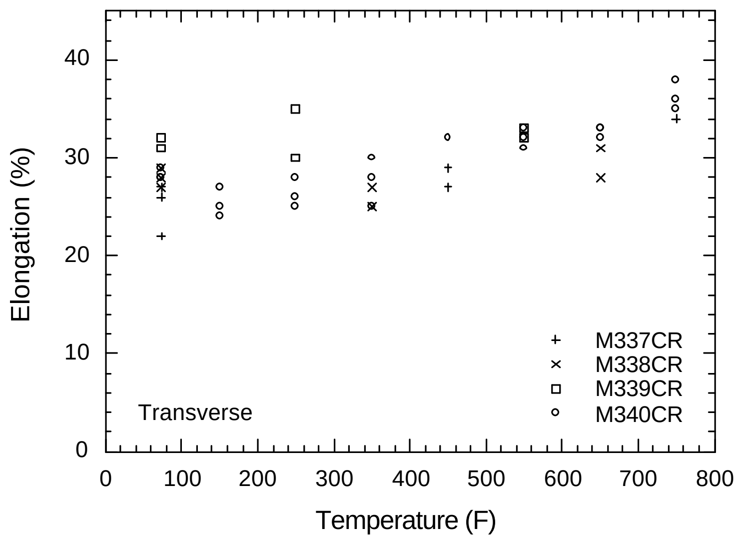
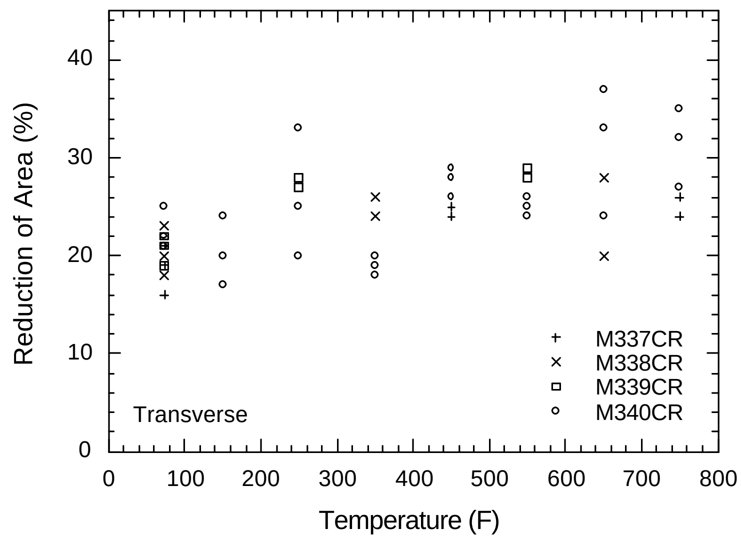
Transverse Tensile Data for Cross Rolled Heats (contd)





Microstructural Features and Corrosion Performance

- The Ni-Cr-Mo alloys are highly resistant to corrosion.
- Alloy 22 (waste package outer barrier material) is an alloy of this type.
- There is no solubility of Gd in austenite matrix of Ni-Cr-Mo alloys
- A Gd rich, eutectic, secondary phase forms— $(Ni,Cr)_5Gd$
- This second phase may be selectively attacked in some projected YMP in-drift environments
- The two-phase structure differentiates these alloys from other Ni-Cr-Mo alloys

Electrochemical Corrosion Test Results

- Potentiodynamic test results show acidic chloride solutions and J-13 will initially remove gadolinide $(Ni,Cr)_5Gd$ and gadolinium oxide (Gd_2O_3) that intersect the surface.
  - Alloy will then repassivate and experience a very low corrosion rate
  - Localized corrosion performance is better than a borated stainless steel in acidic, aggressive environments
  - General corrosion performance should approach that of alloy C-4
  - Accelerated test

Immersion Test Results

Conditions-Heat M322

- ***J-13, 30°C***
- ***6720 hours***

Corrosion rate
20 nm/yr

Conditions-Heat M322

- ***50X J-13, 30°C***
- ***5424 hours***

Corrosion rate
89 nm/yr

Notes:

- ***1 nm = 1 ´ 10^{-9} m***
- ***Alloy 22 rate Is 15 nm/yr in J-13***

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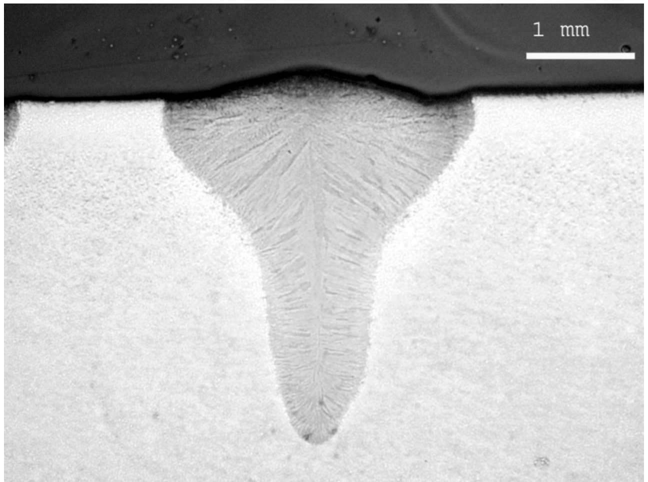
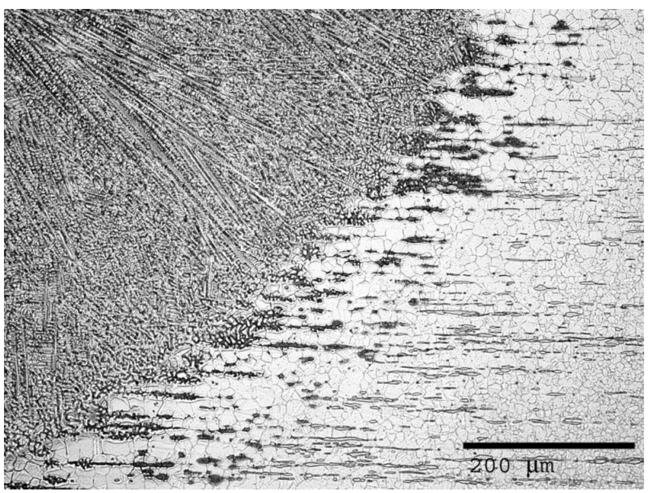
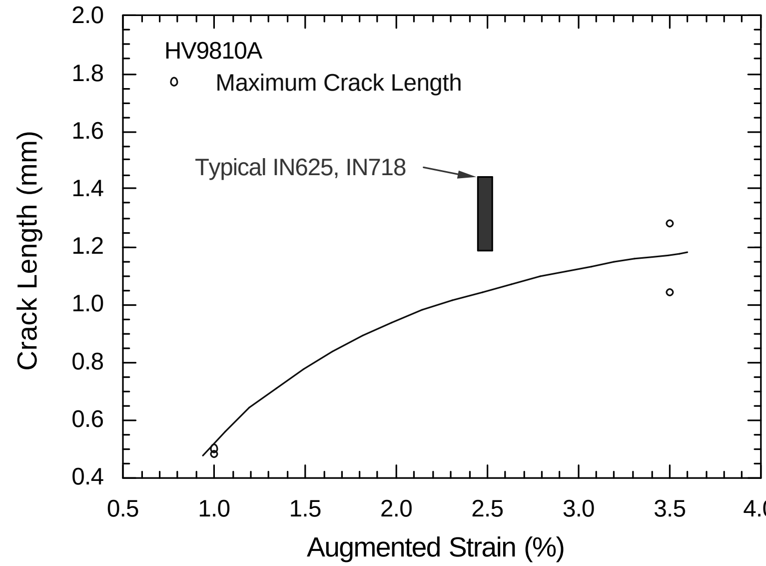
Welding Trials and Weldability

E-beam weld



GTA weld fusion boundary

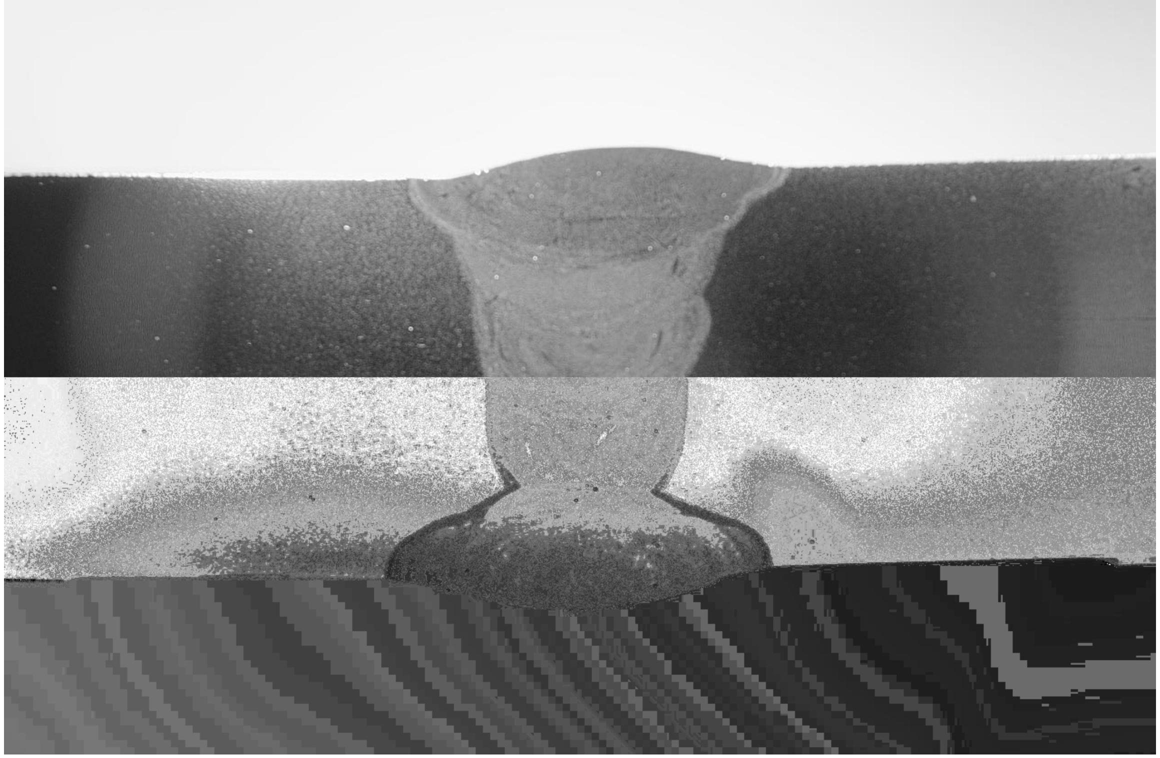




- **Initial electron beam and gas-tungsten arc welding trials are promising**
- **Varestraint tests indicate response is favorable in comparison with other commonly welded Ni-based alloys**
- **Behavior is commensurate with melting temperature range**

Weld Cross Section, M326

- **Heat M326**
- **GTAW Process**
- **0.550 inch plate**
- **VDM 59 weld wire**



FY-05 Plans

- Address ASME questions on Code Case Inquiry
- Weld procedure qualification per ASME
- Heat treat studies for welded construction
- Develop mechanical properties data for ASME Code Case Inquiry for welded construction
- Corrosion testing in newly projected Yucca Mountain Waste Package In-Package solution chemistries
- Address scale up to larger heat sizes

Summary

- Ni-Cr-Mo-Gd alloys can be made with conventional ingot metallurgy techniques and fabricated into structural shapes such as plate
- The alloys will meet all performance requirements
  – ASTM Standard B 932 approved
  – ASME Code Case Inquiry submitted
  – As previously reported, criticality control during regulatory period is assured based on corrosion and neutronic testing
  – Initial welding results are favorable